Improving MANET routing with satellite out-of-band signaling

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Improving mobile ad hoc network routing with satellite out-of-band signaling

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SUMMARY

Routing in mobile ad hoc networks is a complex task due to the mobility of the nodes and the constraints linked to a wireless multihop network (e.g., limited bandwidth, collisions, and bit errors). These adverse conditions impair not only data traffic but also routing signaling traffic, which feeds route computation. In this contribution, we propose to use satellite communications to help in the distribution of mobile ad hoc network routing signaling. The optimized link-state routing (OLSR) is chosen among several routing protocols to be extended with satellite-based signaling, yielding a version we call OLSR hybrid signaling (OLSR-H). This new scheme is evaluated through simulations and yields improvements of approximately 10% in the data delivery ratio compared with a regular OLSR. This evaluation is conducted using two different network topology models, one being fit for representing forest firefighting operations.

KEY WORDS: routing; ad hoc networking; emergency; satellite; OLSR

1. INTRODUCTION

Mobile ad hoc networks (MANETs) have been a subject of research in the last decade. Such networks are made of user terminals without infrastructure nodes (i.e., dedicated routers) and are suitable for quick and low cost deployments. MANETs are proposed for a wide range of scenarios, from spontaneous networks to emergency and rescue operations. They are not, however, without challenges and routing is one of them as the dynamic network topology tends to make routing a difficult task. Commonly, satellite systems are considered as a natural extension of MANETs because of their global coverage. In this respect, they play a role by bridging isolated nodes or interconnecting the MANET with an external network such as the Internet [1].

We propose an alternate approach to satellite-MANET cooperation by creating a satellite-based overlay network for transporting the signaling traffic of MANET routing protocols. This technique is also referred to as *out-of-band signaling*. Out-of-band signaling has been used in other contexts such as contention control for wireless networks [2]. In our work, out-of-band signaling is expected to yield two advantages. First, by improving signaling distribution, routing decisions—which rely on topical signaling information—should also be improved. Second, the use of out-of-band signaling will alleviate the load on the terrestrial network, freeing resources for the user data traffic. Research [3] shows how frequent MANET routing signaling may decrease the overal performance of a MANET. The required satellite resources (transponder capacity, individual terminal throughput) are expected to be low. This expectation will prove to be right as shown later.

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Section 2 covers the MANET models that are used in this work. Section 3 analyzes how satellites may help the routing process of MANETs and discusses the selection of optimized link-state routing (OLSR) as candidate protocol for evaluation. Section 4 presents in detail the outcome of our performance evaluation. The paper closes with a summary of our contributions and some perspectives.

2. TOPOLOGY AND MOBILITY MODELING

Mobile ad hoc networks support a wide range of application scenarios. Examples are self-organized communication during events, sensor data collection, battlefield communications, and emergency communications for rescue operations. When it comes to the performance evaluation of the underlying protocols, a corresponding topology and mobility model must therefore be devised.

A common solution is to choose a generic, random model to represent the dynamic topology of the MANET. Generic models are further subdivided into entity and group models. With entity models, node move independently from each others. In group models, groups of nodes form clusters displaying a similar behavior in terms of motion pattern. A generic entity model called *random waypoint* (RWP) is used in this contribution because it is a popular mobility model for MANET evaluation (66% of MobiHoc 2000–2005 proceedings papers [4]). Although generic models such as RWP are interesting to infer general characteristics, the results they yield are hardly representative of any actual application scenario [5]. For this reason, the present contribution also makes use of a second model called *fire mobility* that represents the deployment of firefighters during forest firefighting operations. The following sections cover the description of these generic and specific models.

2.1. A generic model (random waypoint)

Random waypoint is a mobility model where network nodes are dispatched randomly in a rectangular playground and move independently from each others in a sequence of straight lines. The direction of motion is randomly chosen among 360°, and the speed of motion is also random between 0.02 and 0.05 times the radio range per second. The playground size is bounded as specified later. Our model also assumes that all nodes are equipped with Wi-Fi (IEEE 802.11g) interfaces with a transmitted power of 0 dBm at 2.4 GHz. Channel propagation is characterized using free-space loss where a path loss coefficient α is added (here, α is set to 2).

$$L_{\mathrm{FS}}(\mathrm{dB}) = 10 * \log_{10}\left[R^{\alpha} * \left(\frac{4 * \pi}{\lambda}\right)^{2}\right] \tag{1}$$

L_{FS} is the power loss (dB), R is the distance between the emitter and receiver (m), and λ is the wavelength of transmission (m). The MAC and PHY models are those of the OMNeT++ and INETMANET simulation frameworks [6]. The resulting radio range is in the order of 314 m.

Two metrics are proposed in [7] to classify and validate RWP-based models: network partitioning and shortest path hop count (SPHC). The mean network partitioning accounts for the percentage of node pairs (source and destination) that are disjoint because no route exists. Considering the application scope of this study, the model should display low values of network partitioning. Kurkowski *et al.* [7] proposes a maximum partitioning value of 5%. See [8] for a study on the use of satellite communications to repair network connectivity. The mean SPHC measures the mean number of links (i.e., hops) of the shortest paths among all node pairs. The model should display large values of SPHC in order to assess to its full extent the behavior of MANET routing. Kurkowski *et al.* [7] proposes a minimum value of four hops.

The targeted values of partitioning (<5%) and mean SPHC (>4 hops) yield for this model a network size of at least 95 nodes and a square-shaped playground of side length equal to 6.65 times the radio range. However, considering our simulation environment and available computing power, the ratio of computer time versus simulated time is then equal to 25:1, which makes achieving valid results out of reach. The number of nodes is therefore scaled down to 50 nodes. The playground size is also

Table I. Network metrics of the generic and specific models.

Metric		Generic model	Specific model
Partitioning	Mean	5%	4%
	Standard deviation (time)	6%	12%
Number of neighbors	Mean	7.5	5.5
	Standard deviation (nodes)	3.7	2
Shortest path hop count	Mean	3	3
	Standard deviation (nodes)	1.5	1.6
Link lifetime	Mean	27 s	180 s
	Standard deviation (links)	30 s	400 s

Table II. Route metrics according to the source/destination pairs for the generic (1R, 2R, 3R, 4R, and 5R) and the specific (tank000-tank001, GCC02-GCC00, and GCC01-GCC02) models.

	SRHC		Route lifetime	
Source destination	Mean	Standard deviation over time	Mean	Standard deviation over routes
1R	1	0	Inf	—
2R	3.1	0.3	7.6 s	7.3 s
3R	4.3	0.5	3.8 s	4.2 s
4R	5.7	0.7	2.7 s	3 s
5R	7.2	0.7	2 s	2.3 s
TANK000-TANK001	1.7	0.8	84 s	118 s
GCC02-GCC00	4.4	1.4	18 s	26 s
GCC01-GCC02	6.8	1.1	13 s	20 s

SRHC, shortest route hop count.

decreased to five times the radio range so to keep partitioning below 5%. As a result, the constraint on the SPHC metric is not fulfilled anymore because it is equal to three hops while it should be larger than 4. To circumvent this issue, a two-step approach is taken. First, only the routes corresponding to eligible source and destination account for the SPHC hence renaming this metric to shortest route hop count (SRHC). Next, the pair of nodes acting as source and destination of the data traffic is fixed (i.e., not mobile). By choosing which nodes serve as source destination, it is then possible to set the length of the active routes and to study how the routing protocol performs according to several route lengths. Five different variations are considered with increasing source destination distances from 1 to 5 times the radio range. These variations are named 1R to 5R. Doing so relaxes the simulation computing requirements by 90% because only 50 nodes are needed to evaluate the routing protocol for routes up to seven hops (variation 5R). The resulting topology and route metrics are summarized in the next section together with those of the specific model (Tables I and II).

2.2. *A specific model: forest firefighting*

During forest fires, the operation of public and private networks (if any) might be disrupted. In this context, the use of a MANET together with access gateways to remote core networks has to be considered. Command and control, voice communication, transport of sensor data, and distribution of updated geographical information are among the applications useful to firefighters and first responders.

We designed a topology model on the grounds of field guides [9] and interviews with personnel from the Civil Protection. The basic team unit is the intervention group (IG). An IG is made of the following personnel and vehicles: (i) a group command car vehicle with an IG leader and a driver and

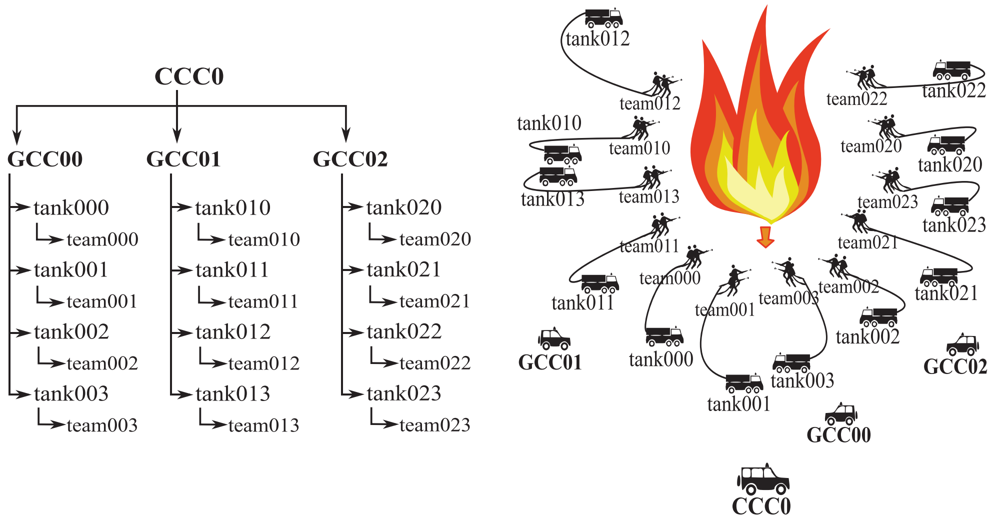

Figure 1. Left: hierarchy of deployment. Right: deployment of firemen and equipments according to the fire. The fire direction of motion is indicated by the arrow. CCC, column command car; GCC, group command car; tank, tanker truck; team, firemen team.

(ii) four tanker trucks each embarking a leader, a driver and two firefighters. A group amounts to a total of five vehicles and 18 personnel.

Depending on the magnitude of the fire, IGs can be organized into columns made of three IGs and a column command car. Columns can be further aggregated into sites, composed of three columns in addition to command and a support elements. A mobility model called fire mobility was devised [10] modeling how a column of firefighters is deployed and moves relatively to the fire. The hierarchy of a column is represented in Figure 1 with a typical deployment. A unit in the column is a node in the corresponding MANET (28 network nodes for a column). Teams are possibly re-deployed as the fire move (every 10 s) so to comply with operational and safety rules.

Similar to the generic model, network nodes are assumed to embark Wi-Fi interfaces. However, the specifics of transmission in a forest environment have also to be accounted for. The Weissberger model [11] models foliage impairment:

$$L_{\mathrm{weiss}}(\mathrm{dB}) = \begin{cases} 0.45 * f^{0.284} * x & \text{if } 0 \leqslant x \leqslant 14 \text{ m} \\ 1.3 * f^{0.284} * x^{0.588} & \text{if } 14 < x \leqslant 400 \text{ m} \end{cases} \tag{2}$$

L_{weiss} being the additional power attenuation due to foliage (dB), f the transmitted frequency (GHz), and x the depth of foliage along the path (m). The computational load of this model is demanding as it is repeatedly used throughout the simulation. We decided to model the foliage attenuation by increasing the α coefficient of the path loss model (Equation 1) used in the generic model so to match the characteristics of the free space loss plus the Weissberger model. Figure 2 shows the received power curves of the path loss and path loss+Weissberger models for the frequency and transmitted power ($f = 2.4$ GHz, $p = 0$ dBm). We choose $\alpha = 3$ as path loss coefficient because the resulting curve best fits the Weissberger model within the sensitivity range of the Wi-Fi transceiver.

Tables I and II show the network and route metrics for the generic and specific models. In the specific model, three different pairs of source destination are selected in order to provide for the increasing route lengths. These pairs are two tankers of the same group, two command cars of neighboring groups, and two command cars of distant groups.

The next paragraphs discuss which routing protocol is adequate for the present study on the basis of how route information is used in the process of route computation.

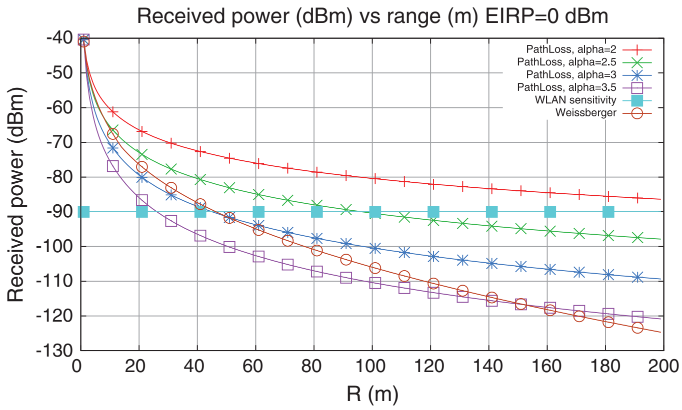

Figure 2. Received power versus distance for the Weissberger and path loss models ($\alpha = 2$, 2.5, 3, and 3.5) considering a 0 dBm transmitted power.

3. ROUTING PROTOCOL AND SATELLITE-BASED SIGNALING

3.1. Routing protocol election

Routing protocols are categorized based on the scope of information they require for route computation: local information, neighborhood information, or network-wide information. For the two latter cases, a companion signaling traffic is required that circulates the information, notifying about nodes and links going up, down, and being congested.

Among the routing protocols requiring network-wide signaling, the family of link-state routing builds a topological map of the network upon which is applied shortest path computation. Link-state protocols are also designed in a modular way: there is a clear split between the route computation process and the signaling information process (which is not the case for distance vector protocols), making it easier to treat separately user and signaling traffic. OLSR is chosen as it is a popular MANET link-state routing protocol. We introduce two new variants of OLSR: OLSR-SAT and OLSR-H ('H' standing for hybrid). As detailed in the succeeding text, OLSR-SAT assumes quite unrealistically that every node in the network includes satellite transmission capabilities. Although this assumption has no real-world counterpart, it provides baseline results used for further comparisons. Conversely, OLSR-H is implemented in a reduced set of nodes (typically, some of the vehicles in the fire mobility model) having satellite capabilities, hence the term *hybrid* because signaling traffic will be circulated by satellite and terrestrial means.

3.2. OLSR-SAT

OLSR-SAT is directly derived from OLSR. To gather information about its environment, OLSR performs two main tasks: link sensing and link-state distribution. Link sensing relies on local exchanges (*hello* messages) to discover the neighbor topology up to two hops far. Link-state distribution is achieved by broadcasting in the entire network topology control (*tc*) messages using multipoint relays (MPRs). MPRs are selected by each network node among neighbors. MPRs are also used to forward data packets.

OLSR-SAT bases the link-state distribution process on the use of a broadcast satellite channel that connects every node in a full mesh topology. In practice, this is achieved by having all nodes registered to an IP multicast address, which is then used to periodically send the *tc* messages. We assume the use of a geostationary satellite with an L-band payload. The use of low-earth orbit constellation is not considered here but would make sense. It is also assumed that satellite transmissions are error free (with current technologies possible through intensive source and channel coding) and that the end-to-end delay for sending a *tc* message is the propagation delay (here a single hop, i.e., 250 ms). Section 4.3. will show that as far as routing performance is concerned, the primary factor driving

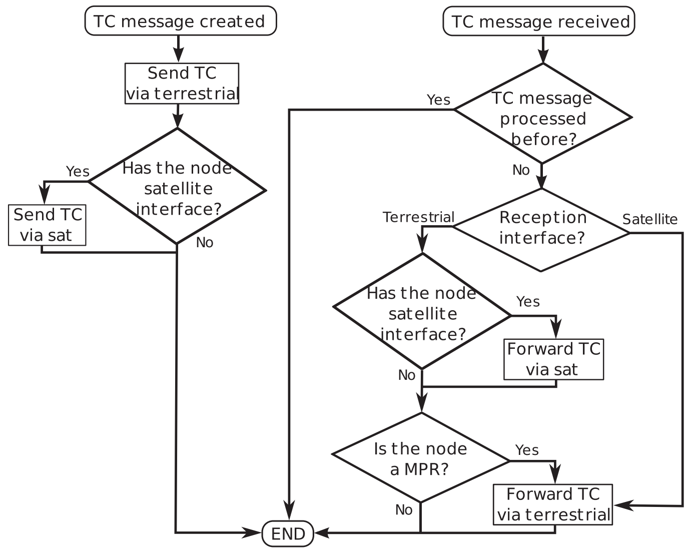

Figure 3. Relaying of *tc* messages by OLSR-H.

routing performance is the reliability of signaling distribution rather than the delay. Finally, Section 4.4. provides an evaluation of the required bandwidth and shows that it is both technically and economically sound because the signaling traffic that goes through the satellite link is less than 1 kbit/s per network node.

3.3. OLSR-H

Although OLSR-SAT requires every node in the network to be equipped with a satellite terminal, OLSR-H operates in hybrid mode. Nodes that do not have satellite capabilities operate like standard OLSR nodes. Nodes with satellite capabilities behave like OLSR and OLSR-SAT nodes. As a consequence, *tc* messages received by terrestrial means are relayed via satellite when possible. Figure 3 shows how *tc* messages are processed by OLSR-H.

The next section covers the evaluation of OLSR, OLSR-SAT, and OLSR-H based on the topology models described previously.

4. EVALUATING ROUTING PERFORMANCE

This section first describes the simulation scenarios that are considered. Then, the performance of routing is evaluated at the light of the different schemes (OLSR, OLSR-SAT, and OLSR-H).

4.1. Simulation scenarios

Two scenarios are implemented with the OMNeT++ simulation framework. The scenarios are based on the models presented earlier: a generic scenario (50 nodes, RWP) and specific one (28 nodes, fire mobility). For the generic scenario, only OLSR and OLSR-SAT are considered. The aim is to identify the relations between signaling and routing performance. For the specific scenario, OLSR, OLSR-SAT, and OLSR-H are compared. Because OLSR-H mixes terrestrial and satellite signaling, three cases are considered as to which units—and therefore network nodes—are equipped with a satellite terminal:

1. All units are equipped ($r = n = 28$ with r the number of satellite equipped units and n the total number of units). All nodes can transmit and receive from the satellite interface. Similar to OLSR-SAT, it is not a realistic option however the results serve as reference. OLSR-H ($r = 28$) is different from OLSR-SAT because in the latter, signaling is solely transported through the satellite channel.

Table III. Scenario characteristics.

	Generic	Specific
Network model and mobility	Generic (random way point)	Specific (fire mobility)
Playground size	200×200 m	
Number of nodes	50	28
RF propagation	Path loss model (EIRP 0 dBm, $\alpha = 2$)	Path loss (EIRP 0 dBm, $\alpha = 3$)
RF range	314 m	46 m
WLAN MAC and PHY	IEEE 802.11g	
Routing protocol	OLSR, OLSR-SAT	OLSR, OLSR-SAT. OLSR-H with 4, 7, and 28 satellite terminals
Source and destination	Fixed, distance from 1 to 7 hops	Mobile, distance from 2 to 7 hops
Traffic profile	1000 B packets sent every 100 ms (exponentially distributed intervals)	
Simulated duration/repetitions	5000 s / 20	6000 s / 20

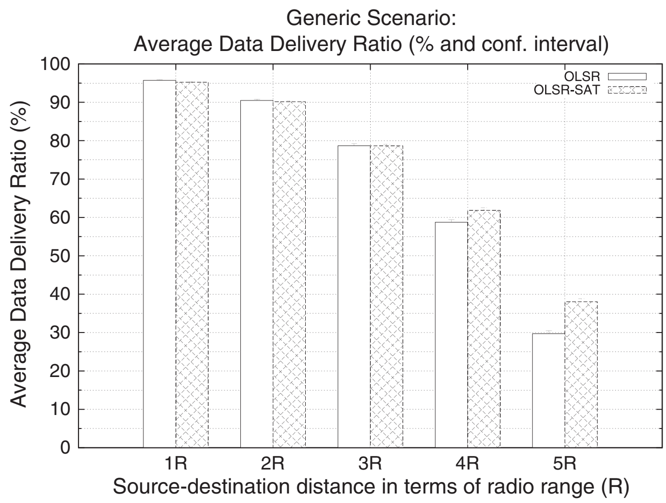

Figure 4. Generic scenario: data delivery ratio for OLSR and OLSR-SAT as a function of the distance between source and destination (95% confidence interval).

2. Four terminal units ($r = 4$). The column command car and the command cars of the three IGs can transmit and receive from the satellite interface. They are chosen because of their position in the organization hierarchy. These vehicles can be equipped with marine-like dishes considering energy supply and antenna mounting constraints.
3. Seven terminal units ($r = 7$). One tanker of each IG is equipped in addition to the command cars.

Table III summarizes the characteristics of the scenarios.

4.2. Generic scenario: comparing OLSR and OLSR-SAT

This section presents the routing performance for the generic scenario and shows that compared with OLSR, OLSR-SAT improves the packet delivery ratio for routes where the source and destination are distant from five hops and more.

Figure 4 shows for OLSR and OLSR-SAT the data delivery ratio between the source and destination as a function of the distance between these two. Two effects are correlated to the length of the route. First, a decrease—regardless of the signaling scheme—of the data delivery ratio is observed as the route length increases. It is the result of the discrepancy between the actual network conditions and

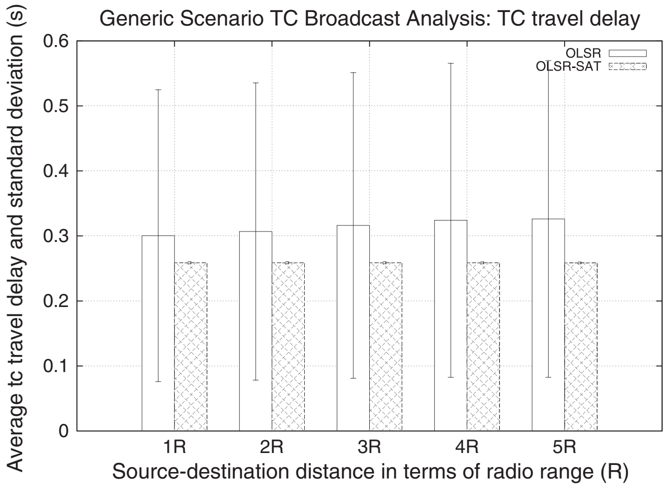

Figure 5. Generic scenario: mean and standard deviation of *tc* messages travel delay (s) for OLSR and OLSR-SAT. The distance between the source and the destination of data traffic varies from 1 to 5 times the radio range.

what is known to the routing protocol. Indeed, the larger the number of hops on the route, the more likely the route lifetime (Table II) to be smaller than the period between two link-state update (5 s). As a result, 'no route to host' events increase significantly as routing entries are obsoleted by failed links prior to the next link-state update process (see Figure A1 in Appendix I).

The second effect observed is the improvement in delivery ratio obtained with OLSR-SAT as the route length increases. Indeed in OLSR, *tc* messages that come from 'a long way' are repeatedly exposed to losses and corruption—as data packet are—therefore leading to incomplete routing table updates. It results, for example, in data packets dispatched to a dead end. On the other hand, OLSR-SAT does not improve the conditions in the network per se, but it suppresses the impairments affecting the signaling traffic. Still, the term impairment has to be clarified because terrestrial signaling is impacted both by delay and packet loss.

Figure 5 shows the mean travel delay for *tc* messages; it corresponds to the mean duration required for a *tc* message sent from a node to reach another node in the generic scenario. It is an indicator of how long a node has to wait before being notified of a change in the network conditions. For OLSR-SAT, the delay is fixed as it only depends on the propagation delay (250 ms). For OLSR, the delay is highly variable because of the variable number of hops a *tc* message must go through. In each hop, a random waiting time (uniformly picked between 0 and 250 ms although RFC 3626 suggests 500 ms as upper bound) called *jitter* is introduced to avoid unwanted synchronizations. Therefore the *tc* messages received in nodes that are far from the *tc* originator arrive earlier via satellite than via terrestrial despite the long delay introduced by the satellite link.

Figure 6 shows the mean *tc* message delivery ratio, the ratio of network nodes receiving a given *tc* message. By inspecting closely the content of the routing tables, it appears that OLSR routing tables lack more entries than OLSR-SAT, that is, some destinations display a 'no route to host' label. This phenomenon is more frequent for entries corresponding to remote destinations. Hence, the impact on the data delivery ratio corresponding to routes that are longer as shown in Figure 4.

OLSR-SAT major contribution is therefore on the enhanced robustness of signaling transport. It impacts routing performance in terms of delivery ratio of user data.

4.3. Specific scenario: comparing OLSR, OLSR-SAT, and OLSR-H

In this section, a similar study is conducted by evaluating the performance of OLSR, OLSR-SAT, and OLSR-H in the context of the firefighting scenario. Unlike the generic scenario, source and destination nodes are mobile. Table II summarizes the route characteristics based on the source and destination.

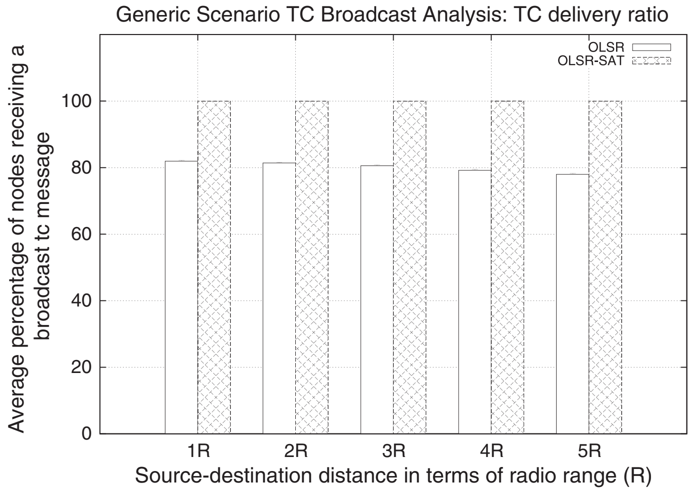

Figure 6. Generic scenario: mean and standard deviation of *tc* messages delivery ratio measured for OLSR and OLSR-SAT. The distance between the source and the destination of data traffic varies from 1 to 5 times the radio range.

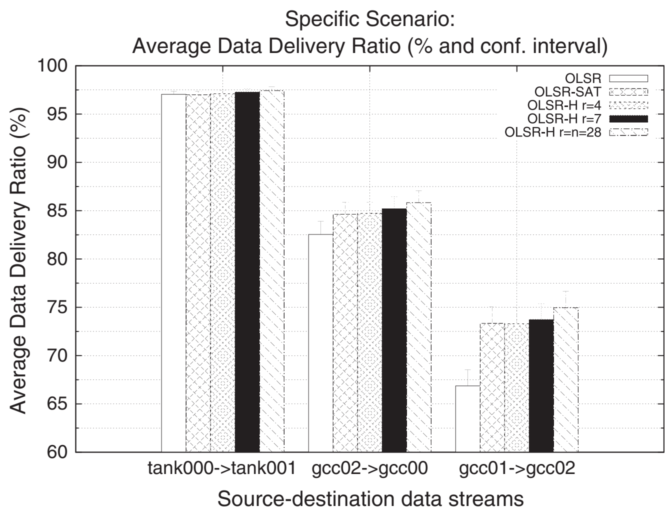

Figure 7. Specific scenario: data delivery ratio for OLSR and OLSR-SAT and OLSR-H as a function of the distance between source and destination (95% confidence interval).

Two questions arise: what is the impact of the specific model and how OLSR-H behaves compared with OLSR-SAT?

Figure 7 shows the data delivery ratio for OLSR, OLSR-SAT, and OLSR-H (with 4, 7, and 28 satellite terminals). Three source/destination pairs are chosen with increasing distance: 1.7, 4.4, and 6.8 hops. Compared with the generic scenario, the data delivery ratio is on the average better. Indeed, although RWP (in the generic model) yields frequent link setup/teardown hence shorter route lifetime (Table II), fire mobility displays stable links at least within a group. As observed with the generic scenario, the improvement in data delivery ratio is visible only for long distance routes (more than four hops). It is also worth noting that OLSR-H with four satellite terminals displays the same delivery ratio as OLSR-SAT where all nodes are equipped with satellite terminals. It is a direct consequence of the hybrid approach of OLSR-H as it brings the ‘best of both worlds’: neighbor *tc* messages get delivered by terrestrial means, farther messages or those that were lost during their terrestrial journey are delivered via satellite.

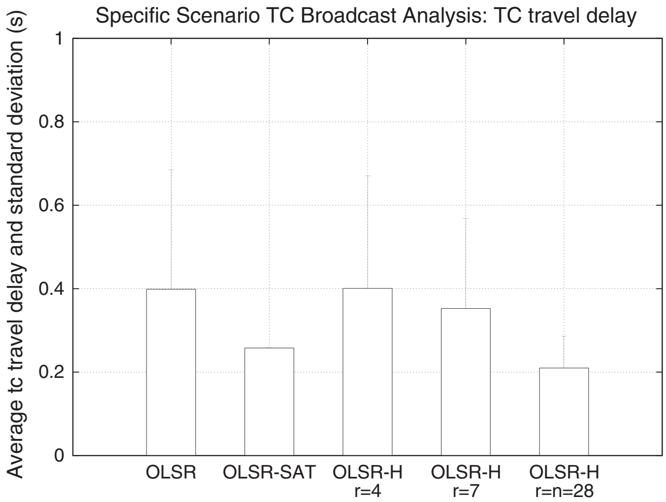

Figure 8. Specific scenario: mean and standard deviation of *tc* messages travel delay (s) for OLSR, OLSR-SAT, and OLSR-H. These results are independent of the distance between the source and destination.

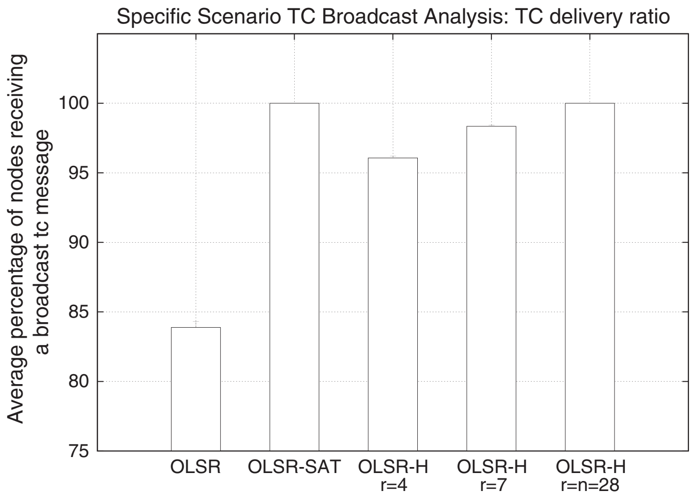

Figure 9. Specific scenario: mean and standard deviation of *tc* messages delivery ratio (s) for OLSR, OLSR-SAT, and OLSR-H. These results are independent of the distance between the source and destination.

As for the *tc* travel delay, Figure 8 shows the mean and standard deviation for OLSR, OLSR-SAT, and OLSR-H. It is worth noting that OLSR and OLSR-H ($r = 4$) features similar delay characteristics, although Figure 7 showed that OLSR-H improves the data (i.e., not *tc*) delivery ratio by 5%.

Figure 9 shows that what makes the difference and explains the superior performance of OLSR-H over OLSR is the improved—more than 10%—reliability of *tc* message delivery. The criticality of signaling reliability is confirmed by observing the results of OLSR-SAT: although the signaling travel delay is significantly smaller than OLSR or OLSR-H $r = 4$, OLSR-SAT and OLSR-H signaling delivery ratios are comparable (100% vs. 97%) and so is the data delivery.

Again, we can conclude that the major contribution of satellite-based signaling distribution in the specific scenario is not on the delay but rather on improving the reliability of this important control traffic. The next section investigates about the signaling overhead generated by the different signaling schemes.

Table IV. Specific scenario: mean signaling traffic (in bytes/s) per node for OLSR, OLSR-SAT, and OLSR-H.

	OLSR	OLSR-SAT	OLSR-H ($r = 4$)	OLSR-H ($r = 7$)	OLSR-H ($r = 28$)
hello messages in bytes/s/node	27	27	27	27	27
tc messages (WLAN) in bytes/s/node	48	0	62	69	104
tc messages (SAT) in bytes/s/node	0	5	70	64	52
Total *tc* over sat traffic in bytes/s	0	140	280	448	1456

4.4. *Specific scenario: evaluating the signaling overhead*

It has been shown that OLSR-SAT and OLSR-H $r = 4$ perform similarly as far as data delivery ratio is concerned. The data delivery is improved over what is observed with OLSR where no satellite is used. Table IV shows for the specific scenario the traffic (in bytes/s) per node dedicated to the transport of *hello*, *tc* over terrestrial link and *tc* over satellite link.

Disregarding how economically unfeasible it can be, OLSR-SAT is the ideal solution as long as signaling overhead is concerned: multihop terrestrial *tc* signaling is replaced by a single *tc* message broadcast via satellite yielding a 40 bit/s traffic per satellite terminal. OLSR-H, on the other hand, calls for additional satellite resources as it requires a maximum of 560 bit/s (per satellite terminal), which is tractable. It also displays an additional terrestrial overhead compared with OLSR. This latter effect is due to a sub-optimal *tc* forwarding algorithm (Figure 3) where two identical *tc* messages may get forwarded both on the terrestrial and satellite interfaces because of race conditions. We believe that there is still room for improvement without degrading the overal routing performance. However, it is important to note that even without further optimization, the overall signaling traffic going through the satellite does not exceed 12 kbit/s in the worst case (OLSR-H $r = 28$).

5. CONCLUSIONS

In this article, we have investigated how routing in MANETs can be improved through the use of satellite-based signaling distribution. Three contributions can be derived from this work. The first contribution relates to the impact of signaling traffic over routing performance: reliability is the key aspect above the need to deliver quickly signaling information. A second contribution is the proposal and evaluation of a hybrid signaling scheme (OLSR-H) that mixes terrestrial and satellite-based signaling in order to achieve an improvement of the data delivery ratio. It has been shown that OLSR-H is also economically sound because it requires a reasonable amount of satellite bandwidth. The last contribution is the use of a realistic network and mobility model—namely fire mobility—for evaluation while most papers in the literature rely on generic models.

The perspectives for this work are as follows: first, forwarding of signaling in OLSR-H can still be further optimized in order to avoid redundant transmissions on the terrestrial and satellite links. Second, the transmission of *tc* messages is currently carried out on a periodical (every 5 s) basis. It would make sense to evaluate a triggered approach where upon failure of a link, an urgent signaling message is sent via satellite. Lastly, mechanisms for improving the reliability of (plain) OLSR signaling should be sought either through error coding mechanisms or priority-based resource management.

APPENDIX I

This figure is put in the appendix in order to improve the flow of text.

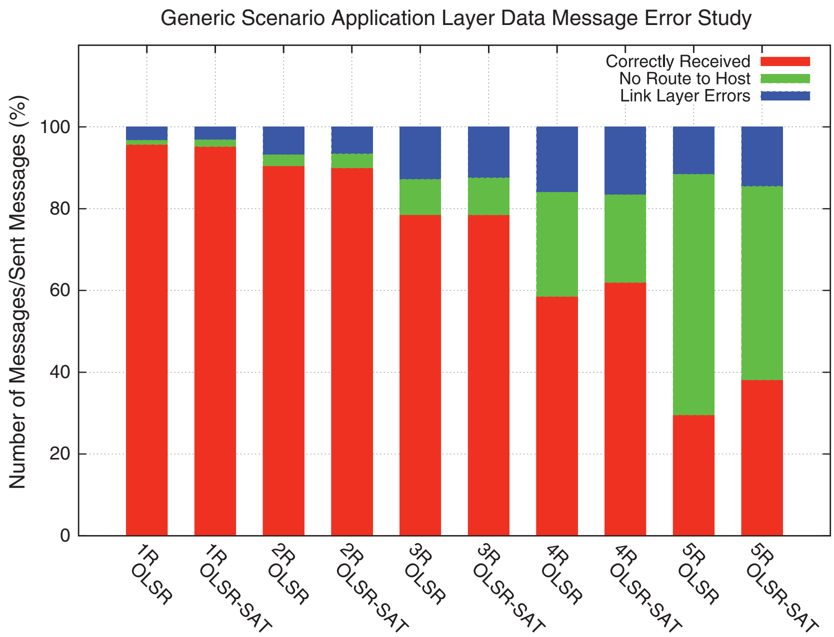

Figure A1. Generic scenario: categories of errors impacting data packets for OLSR and OLSR-SAT. The distance between the source and the destination of data traffic varies from 1 to 5 times the radio range.

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